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Phytochemicals, antioxidant activity and nutritional profile of pulp, peel and peel fiber of mango (*Mangifera indica* l.) cultivar Ataulfo

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Submission Date: September 3rd, 2024; **Acceptance Date:** October 10th, 2024; **Publication Date:** October 15th, 2024

Please cite this article as: Please cite this article as: Vélez de la Rocha R., Sañudo Barajas J. A., Chaidez-Quiroz C., Cárdenas Torres F. I., Teran Cabanillas E., Vergara-Jiménez M. J. Phytochemicals, antioxidant activity and nutritional profile of pulp, peel and peel fiber of mango (Mangifera indica L.) cultivar Ataulfo. Functional Foods in Health and Disease 2024; 14(10):713-727. DOI: https://doi.org/10.31989/ffhd.v14i10.1449

ABSTRACT

Introduction: Mango fruit and its by-products represent a very diverse and abundant source of sugars and components with anti-inflammatory and antioxidant properties, such as dietary fiber, vitamins, and polyphenols. Consuming mango pulp might reduce health disorders caused by inflammatory and oxidative processes such as obesity related diseases. Mango and its by-products contain compounds that can either promote or neutralize inflammatory and oxidative environments; variations in their composition may directly influence the degree of bioactivity. This work aimed to analyze the nutritional and nutraceutical profiles presented in the three different mango by-products to know their possible nutraceutical potential.

Objective: This work aimed to analyze the nutritional and nutraceutical profiles presented in the three different mango by-products to know their possible nutraceutical potential.

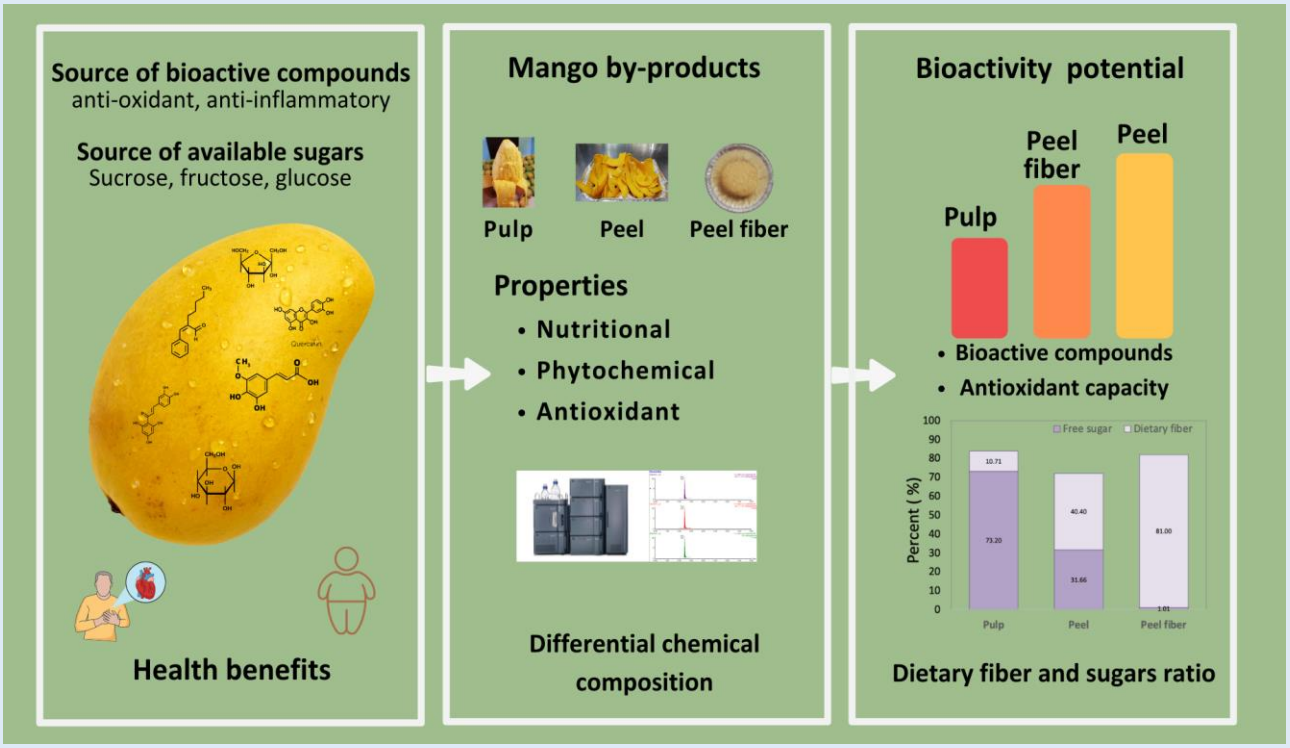
Methods: Ripe Ataulfo mango products (pulp, peel, and peel fiber) were evaluated for nutritional composition by AOAC methods. β-carotene and ascorbic acid were analyzed by UV-Vis liquid chromatography (LC), while mangiferin, phenolics

and flavonoids by LC coupled to mass spectrometer detector. The antioxidant capacity was correlated to each of the bioactive compounds.

Results: Ripe Ataulfo mango products (pulp, peel, and peel fiber) were evaluated for nutritional, antioxidant, and phytochemical characteristics. All the by-products demonstrated significant differences ($P \leq 0.05$) in nutritional and chemical composition. Mango peel had the highest β-carotene, vitamin C, and mangiferin values. Mango pulp had the highest values for free sugars (73 g 100 g^{-1}), but low phytochemicals values, contrasting the peel fiber with 81% of total dietary fiber but minimum values of free sugars and β-carotene and no vitamin C. The highest antioxidant capacity was presented for mango peel. Results obtained from this study indicate that the mango Ataulfo pulp and by-products are divergent and represent a good source of bioactive compounds.

Conclusions: Mango peel composition is a natural combination of high concentrations of mangiferin, flavonoids, phenolic acids, vitamin C, provitamin A, and dietary fiber, all involved with inflammation and cell oxidative stress-related disease control and prevention. However, mango peel exhibited the most significant nutraceutical potential due to its high antioxidant capacity.

Keywords: *Mangifera indica* L.; Mango Ataulfo; Mangiferin; Flavonoids; Phytochemicals; Bioactive Compounds



Graphical abstract: Phytochemicals, antioxidant activity and nutritional profile of pulp, peel and peel fiber of mango (*Mangifera indica* l.) Cultivar Ataulfo

INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most appreciated tropical fruits in the world, Greater awareness of the health benefits is likely the cause of the increase in mango consumption in the United States and the European Union over the past 5 years [1]. Mango fruit is a rich source of minerals, vitamins, and macronutrients, primarily carbohydrates, which include free sugars (such as fructose, sucrose, and glucose) as well as dietary fiber (including cellulose, hemicellulose, and pectins) [2-3]. Free sugars and dietary fiber have entirely different physiological effects on the human body. Monosaccharides and disaccharides represent a readily available energy source when metabolized into glucose, increasing blood glucose levels rapidly after ingestion [4]. On the other hand, dietary fiber is categorized into soluble and insoluble fiber according to the physicochemical properties of different polysaccharide-type molecules that compose them [5]. These polysaccharides are resistant to human digestive enzyme degradation but not to bacterial enzymes of the gut microbiota [6]. Dietary fiber can modulate the gut microbiota, mango consumption increases microbial diversity and favors the production of metabolites that promote health benefits [7]. Dietary fiber is essential for the correct functioning of the digestive system, in addition, the functionality of dietary fiber has been demonstrated in helping to relieve inflammatory processes associated with chronic non-communicable diseases [8-9]. Despite the sugar content of mango fruit, some scientific evidence suggests that consuming mango reduces risk factors associated with health disorders that involve inflammatory and oxidative processes [10-12].

Many non-communicable diseases have their origin in excessive production of reactive oxygen species (ROS), which are derived from some cellular physiological processes such as respiration or inflammatory processes. ROS have at least one oxygen atom and at least one unpaired electron in their structure. The main ROS are superoxide anion radical ($O_2^{\cdot}$-), hydroxyl radical (.OH), hydroperoxyl radical (ROO.), singlet oxygen ($^1O_2$), and nitrogen radicals. The imbalance between ROS production and antioxidant production or intake leads to negative health effects, mainly on the circulatory, respiratory, and nervous systems [13].

Mango fruit is a natural source of many biologically active phytochemicals, such as carotenoids, ascorbic acid, polyphenols, and mangiferin, which promote beneficial effects on human health through their anti-inflammatory effects and antioxidant capacity.

Carotenoids are the pigments responsible for the colors of mangoes, which range from yellow to red or purple. The chemical structure of carotenoids consists of a 40-carbon skeleton formed by eight isoprene units with nine conjugated double bonds, and an end group at both ends of the polyene chain. β-carotene has high activity of quenching of singlet oxygen and scavenging of superoxide anion and peroxyl and hydroxyl radicals [14].

Ascorbic acid (vitamin C), is widely present in many vegetables and fruits, including mangoes. Ascorbic acid is another powerful antioxidant that reduces unstable oxygen, nitrogen, and sulfur-free radicals. Antioxidants protect DNA and lipids from ROS-induced oxidation, preventing cell-damaging mutations [15]. Different *in vitro* techniques are used to determine food's effectiveness or antioxidant potential; for instance, given the chemical diversity of molecules with antioxidant properties, more than one method should be used to measure antioxidant activity in a complex matrix [16].

Phenolic compounds, or polyphenols, are secondary metabolites found in plants. Their chemical structure features one or more hydroxyl groups directly attached to an aromatic ring. Depending on molecular structure, polyphenols are classified into different groups, with phenolic acids, flavonols, flavones, and xanthones being the main groups reported for mangoes [17-18].

Polyphenols are not strictly considered nutrients, but they are crucial to prevent or assist in the treatment of some diseases, mainly those related to inflammation and oxidative stress [19]. Mangiferin is classified as a polyphenol; chemically it is a glucosylxanthone that has two aromatic rings in its molecule. It is found predominantly in steam bark, leaves and fruits of the mango tree [20]. Mangiferin is a molecule with an extraordinary antioxidant capacity. There is evidence of the anti-inflammatory, anticancer, immunomodulatory effects of mangiferin and other related xanthones such as isomangiferin, homomangiferin, isomangiferingallate, mangiferingallate [21].

The mango fruit can be regarded as a natural functional food due to its abundance of biologically active compounds, which are largely responsible for the health benefits demonstrated in various scientific studies [22]. There is increasing research studying the effects and mechanisms of biologically active compounds in mango responsible for human health benefits. Extracted compounds with high pharmacological potential from mango by-products could also contribute to fulfilling the requirements for establishing mango-derived products as functional ingredients. In this regard, positive effects of mangiferin on diabetes, cardiometabolic diseases and metabolic syndrome components have been demonstrated [23-25]. Besides, the use of mangiferin has been explored in other areas such as cosmetics because it has activity against aging and the harmful action of sunlight. [21].

Mango Ataulfo pulp has significantly higher polyphenol content than other commercial cultivars in America [26]. Similarly, Ataulfo mango peels were found to be superior in abundance of bioactive compounds and antioxidant capacity [27]. On the other hand, different amounts and kinds of bioactive and phytochemicals are present in the different mango fruit fractions: pulp, peel, and seeds [28-29]. The composition of fiber isolated from the peel of some mango varieties has been characterized and has revealed an interesting nutraceutical and technological potential [30].

Research for the study and use of mango by-products has constantly increased to find alternative uses because mango by-products are a very rich source of wasted bioactive components and, at the same time, they are a severe problem of environmental contamination.

The nutritional and phytochemical composition of mango and its by-products directly affect the beneficial effects they produce. Further investigations are required to collect sufficient evidence, support the association of mango consumption with health benefits, and determine possible synergistic interactions among various mango constituents. The characterization of by-products derived from mango is the first step in research focused on evaluating the effect of mango components and their by-products as they are naturally interrelated. This work aimed to analyze the nutritional and nutraceutical profiles presented in the three different mango by-products to know their possible nutraceutical potential.

METHODS

Preparation of mango Ataulfo products: Ataulfo mango fruits were harvested at consumption maturity in July 2020 in a commercial orchard in Escuinapa, Sinaloa, Mexico. The fruit was washed with chlorinated water and dried at room temperature before processing. The peel and pulp were separated, frozen at -80°C, freeze-dried, and stored in a desiccator until use. The dietary fiber-rich fraction was obtained from freeze-dried peels by successive washing with 80% ethanol, 96% ethanol, and acetone and oven-dried at 40°C overnight to evaporate the residual solvent.

Macronutrients composition analysis: The percentage of moisture, protein, total lipids, ash, dietary soluble and insoluble fiber and total carbohydrates were determined in triplicate following the official methods (925.10 for moisture, 920.87 for protein, 920.39 for fats, 923.3 for

ash, and 991.43 for total dietary fiber, insoluble dietary fiber, and soluble dietary fiber) according to the official procedures of AOAC [31]. Simple sugars (glucose, fructose, and sucrose) were subjected to extraction [32]. Samples were macerated overnight in aqueous ethanol (80% v/v) followed by 2 h sonication (Branson sonicator), and finally were centrifugated for 10 min at 3,000 x g. Supernatants were used for enzymatic quantification using the Megazyme® KSUFRG kit protocol.

Bioactive compounds analysis: Ascorbic acid (Vitamin C) content was quantified by high-performance liquid chromatography (HPLC) according to the methodology recommended by Gökmen [33]. Briefly, 10 g of the sample was homogenized with 40 ml of cold double-distilled water, the blend was filtered, and 2 ml was mixed with 2 mg of dithiothreitol for one hour at room temperature. Subsequently, it was filtered with a 0.45 µm nylon membrane and injected into an HPLC equipped with a 250 x 4.6 mm Phenomenex C18 column, UV-Vis detector configured at 254 nm. The mobile phase used was 0.2 M phosphate buffer, pH 2.3, delivered at a flow rate of 0.5 ml min^{-1}. Quantification was performed by the external standard method using a calibration curve from 2 to 50 mg/L^{-1} of ascorbic acid (Sigma®).

The β-carotene (provitamin A) content was quantified by HPLC. 5 g of sample were extracted three times, successively with a mixture of methanol-Tetrahydrofuran (1:1), in the presence of BHT as an antioxidant and sodium sulfate as a desiccant. The extracts were subsequently filtered (Whatman No 41 and nylon membrane) before injection into an HPLC (250 x 4.6 mm Phenomenex C18 column, UV-Visible detector at 460 nm). As a mobile phase, a mixture of 55:35:10 acetonitrile:methanol:tetrahydrofuran was used at a flow rate of 1.0 ml.min^{-1}. Quantification was performed by external standard method, the calibration curve was performed from 10 to 100 mg. L^{-1} of β-carotene, (Sigma®) [34].

Free phenolic compounds were extracted by a conventional methanolic extraction [35]. Briefly, 1 g of mango sample powder was homogenized in 25 mL of methanol 80 %, with a dispersing machine at 24 000 rpm for 1 min. Then, the slurry was centrifugated at 4 000 x g, 20 min, 4 °C. Supernatant was kept at −80 °C until the analysis of phenolic acids, flavonoids, and antioxidant activity.

For the chromatographic analysis of phenolic acids, 1 µL of sample was injected into an Acquity H Waters UPLC with G2-XS QTof mass analyzer (quadrupole and time of flight), using a capillary: 1.5 KV and sampling cone: 30, solvation of 800 (L/h) at a temperature of 500°C, collision energies of 10 to 60 V and an electrospray ionization (ESI) source, Acquity UPLC BEH C18 column (1.7µm 2.1 x 100 mm) at 40°C. The mobile phase gradient was 95% A and 5% B at a flow rate of 0.3 mL/min (phase A: acidified water, 0.1% formic acid, and phase B: acetonitrile). Compound identity was confirmed using the Massbank of North America (MoNA) database. Calibration curves of known gallic, ferulic, caffeic, cinnamic, quinic, and coumaric acid concentrations were used for quantitation [36].

For flavonoid quantification, 5 µL of the filtered extract was injected into an Acquity H series UPLC system throughout a Waters Sample Manager–FTN and a BEH Phenyl (1.7µm, 2.1 x 100 mm) column. The mobile phase comprised 5 mM ammonium formate (pH 3.0 and a mix of acetonitrile + 0.1% formic acid. Identification and quantification were performed using ESI probe (+/-) on a Waters Xevo TQ-S mass spectrometer and MassLynx workstation. The ions were monitored using MRM (Multiple Reaction Monitoring) "product ion scanning" for at least two transitions. The identification of individual flavonoids was assigned with the retention time and MRM transitions, and its quantification was calculated using calibration curves of standards at known concentrations [37].

Analysis of antioxidant capacity: Trolox Equivalent Antioxidant Capacity (TEAC) is based on the ability of molecules to scavenge the stable free radical compared with Trolox, a water-soluble analog of vitamin E. The antioxidant activity of a food is then expressed as TEAC units (mM Equivalent Trolox per gram of dry sample) [35]. The antioxidant capacity of the methanolic extracts of the pulp, peel and peel fiber were assayed using three following methods [38]. The three antioxidant capacity assessments were arranged in 96-well plates, as well absorbance and fluorescence measurements were registered using a Synergy HT Microplate reader BioTek.

The presence of the antioxidant compounds in the extracts reduces the absorbance of ABTS (2,2'-azino-bis, 3-ethylbenzothiazoline-6-sulphonic acid) at 734 nm [39]. For the assay, 10 µL of the extract was added to 190 µL of the reaction mix 1:1 (2.6 mM potassium persulfate + 7.4 M ABTS•+), the reaction was then allowed to stand in the absence of light for 2 h and the absorbance at 734 nm was recorded.

The FRAP (Ferric Reducing Antioxidant Power) is based on an antioxidant reaction with a Fe (III) complex; the increase in absorbance at 590 nm was used to calculate the antioxidant activity. 30 µL of samples, standards, and blanks were added to their respective wells; then the plate was incubated in the dark for 4 min after adding 120 µL of FRAP reagent (1 mL of TPTZ 30 mM, 1 mL of FeCl3•6H2O 60 Mm, and 10 mL of acetate buffer).

Finally, the ORAC (Oxygen Radical Absorption Capacity) assay consisted of an antioxidant reaction with peroxyl radicals, produced by 2,2'-azobis-2-amidino-propane (AAPH), fluorescence loss was registered using fluorescein as a fluorescent probe. The reaction mixture was performed in a 96-well microplate with a clear bottom and black walls in which each well contained 25 µL of extract, 75 µL of AAPH 95.8 µM, and 200 µL of 0.96 µM fluorescein in. Prior to the reaction all reagents and samples were incubated at 37 ◦C for15 min. The microplate reader was set to a wavelength of 485 nm for excitation and 580 nm for emission to perform the fluorescein degradation curve over a period of 70 min, reading every 70 s. The Trolox curve used was linear from 6.25 to 125 (µmol TE/g).

Statistical analysis: The experimental design was completely randomized with three replications. Data was analyzed with MINITAB 17 software (Minitab, Inc. State College, PA, USA). One-way ANOVA was performed and differences between means were evaluated using Tukey's method for multiple comparisons and were considered significant at 95 % confidence ($p \leq 0.05$). For the correlation between variables, a Pearson correlation analysis was carried out. The variables were categorized according to the mango product analyzed.

RESULTS

Nutritional Profile: The three mango fractions identified as pulp, peel, and peel isolated fiber (MPF) were characterized and presented a moisture value below 9%. The dry basis percentage of the nutritional values displayed in Table 1 showed that MPF presented a significantly higher percentage of protein and ash ($p \leq 0.05$), while the pulp and peel had similar protein values but differed on ash content, being lower on MP. However, the highest fat content was for the Peel fraction (2.68%) compared with pulp and peel fiber. Carbohydrates were the major component (72 to 80 %) in the fractions of mango Ataulfo; however, their proportion differed significantly among the pulp, peel, and isolated peel fiber (Figure 1).

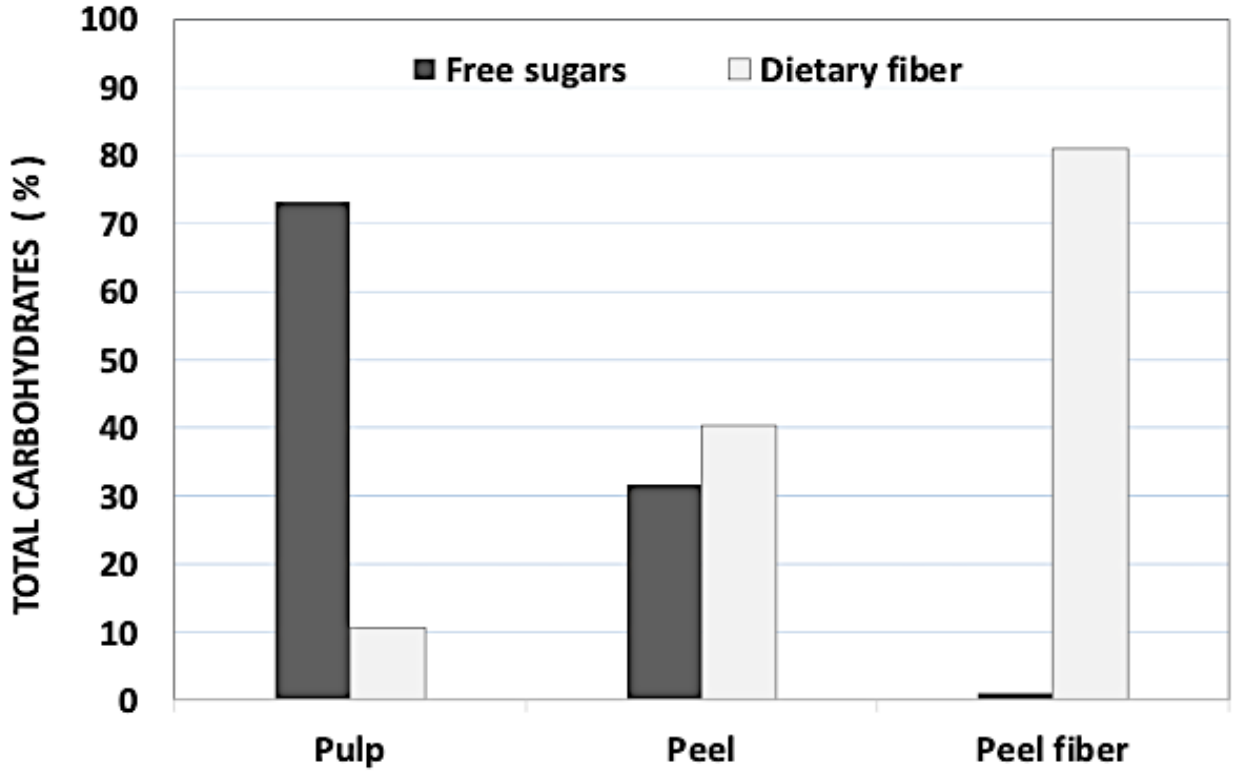


Figure 1. Dietary fiber and free sugars profile of Pulp, Peel and Fiber from peel of ripe mango Ataulfo.

Dietary fiber: Significative differences were found between the three mango sections ($p \leq 0.05$). As expected, the dietary fiber content in the MPF (81 %) was 8-fold the value of MP and twice the peel. However, the proportion of insoluble and soluble dietary fiber did not vary significantly in the mango fractions, with a proportion close to 1:1.

Simple sugars: The content of total simple sugars in the pulp of Ataulfo mango was 71 % vs 31.7 % in the peel. Sucrose was the most abundant sugar, followed by fructose, while glucose was less abundant (Table 1). Sucrose and fructose accounted for about 90% of the total simple sugar content in three fractions. Sucrose reached 52.9 % and 15.3 % values in pulp and peel, respectively; values for fructose in pulp and peel were 15.3 % and 8.2 %, respectively. The sum of sucrose, fructose, and glucose percentages was less than 1% in MPF.

Vitamin C: The ascorbic acid content was considerably high in peel and pulp (1017 and 667 mg 100 g^{-1}), even though vitamin C is very susceptible to oxidation since both the pulp and peel were immediately frozen and then freeze-dried. Significant differences ($p \leq 0.05$) were found in vitamin C content in mango fractions since the peel contained almost double the concentration found in the pulp, but the peel fiber lost the component during the solvent washing and drying process (Table 1).

β-carotene: Regarding β-carotene content, peel presented the highest value (60.4 mg 100 g^{-1}), followed by pulp (44.3 mg 100 g^{-1}), and finally, peel fiber with 1.7 mg 100 g^{-1}. In this case, Table 1 also shows the vitamin A values as retinol activity equivalents (RAE), a conversion factor of 12 µg β-carotene to 1 µg retinol was used, according to the Institute of Medicine (US) (39). Significant differences were observed in the content of β-carotene ($P \leq 0.05$) between the three mango materials evaluated, with the peel being the material that

presented the highest content, followed by the pulp, and finally, the MPF with the lowest level of β-carotene.

Phenolic compounds: In general, peel had significantly higher ($p \leq 0.05$) concentrations of all identified and quantified phenolic compounds (Table 2). Furthermore, pulp and peel fiber significantly differed in all phenolic compounds except coumaric acid ($p \leq 0.05$). The most abundant phenolic acids in the three mango sections were quinic and ferulic, followed by gallic and coumaric; peel values for these compounds were 3 244, 2 650, 149.2, and 5.6 mg 100 g-1, respectively. The peel presented levels of phenolic acids approximately 10-fold higher than peel fiber and 30-fold higher than those observed in the pulp.

Regarding flavonoid quantification, quercetin was the most abundant, reaching a value of 4.0 mg.100g^{-1} in peel fraction, then MPF had 2.5 mg.100g^{-1}, and finally pulp with 0.04 mg.100g^{-1}. According to their abundance, the following flavonoids were luteolin 7-O-glucoside, apigenin glucoside, and quercetin 3-O-rhamnoside. The pulp was the poorest fraction of flavonoid content since the concentrations found were less than 0.05 mg.100g^{-1}. The pulp, peel, and isolated peel fiber were significantly different ($p \leq 0.05$) for each of the flavonoids, except quercetin-3-O-Rhamnoside, which were not found in Pulp fraction, and no differences were shown between peel and peel fiber.

Finally, mangiferin, an important phytochemical of the xanthones group, reached values of up to 1 728 mg.100 g^{-1} in Peel fraction, in second place MPF with 752.1 mg.100g^{1} and the last the Pulp fraction barely quantified 0.8 mg.100g^{-1}.

Table 1. Average percent (Dry basis) and standard deviations (n =3) of the nutritional components in Pulp, Peel and Fiber from peel of ripe mango Ataulfo.

Component	Pulp	Peel	Peel fiber
Water	6.92 ± 0.12 ^{b}	5.38 ± 0.01 ^{c}	8.55 ± 0.09 ^{a}
Protein	3.26 ±0.24 ^{bc}	3.57 ± 0.70 ^{b}	5.31 ± 0.22 ^{a}
Fat	1.29 ± 0.0 ^{c}	2.68 ± 0.02 ^{a}	1.38 ± 0.02 ^{b}
Ash	2.38 ± 0.04 ^{c}	3.98 ± 0.24 ^{b}	6.05 ± 0.04 ^{a}
Carbohydrates			
Total dietary fiber	**10.7 ± 0.73** ^{c}	**40.4 ± 2.71** ^{b}	**81.0 ± 1.69** ^{a}
Insoluble Fiber	4.5 ± 0.6	21.9 ± 0.3	41.0 ± 1.4
Soluble Fiber	6.2 ± 0.12	18.5 ± 3.0	39.9 ± 2.3
Free sugars	**73.2 ± 2.78** ^{a}	**31.7 ± 0.49** ^{b}	**0.94 ± 0.30** ^{c}
Sucrose	52.9 ± 2.5	20.2 ± 0.17	0.70 ± 0.15
Fructose	15.3 ± 0.25	8.2 ± 0.45	0.2 ± 0.04
Glucose	5.1 ± 0.4	3.2 ± 0.06	0.07 ± 0.02
Micronutrients			
Vitamin C (mg/100 g)	667 ± 52.6 ^{b}	1017 ± 32.3 ^{a}	ND
Vitamin A (mg/ 100 g)	44.3 ± 5.3 ^{b}	60.4 ± 5.2 ^{a}	1.72 ± 0.2 ^{c}
µEq. Retinol	369.4 ± 44.0 ^{b}	503.7 ± 43.5 ^{a}	14.4 ± 1.6 ^{c}

Different superscript letters indicate significant difference between treatments ($p < 0.05$).

Antioxidant activity: Mango peel showed significantly higher values of antioxidant activity ($p \leq 0.05$), values of 372.9, 252.1, and 348 mMol TE/g for ABTS, FRAP, and ORAC assays, respectively (Table 3). No differences were found between pulp and peel fiber for any of the three antioxidant activity evaluations. Antioxidant activity values in pulp were 7.1 mMol TE/g for ORAC and ABTS, while those of peel fiber were 8.5 and 9.2 mMol TE/g respectively. Furthermore, higher TEAC values were found when evaluating the antioxidant capacity by FRAP (Table 3), although there were no significant differences between pulp and peel.

To investigate the correlation between the polyphenol content and the antioxidant properties of different parts of mango Ataulfo, Pearson's coefficient was calculated. As shown in Table 4, a significant positive correlation was observed between the mM Equivalent Trolox values of free radicals scavenging activities and individual bioactive components of mango. The strongest correlation was obtained between the phenolic acids (ferulic, quinic, galic, and coumaric) and antioxidant activity since they presented correlation coefficients higher than 0.9 ($p \leq 0.0001$). Mangiferin gave a significantly ($p \leq 0.001$) high positive correlation with ABTS, FRAP, and ORAC assays with Pearson´s coefficient of 0.886, 0.832, and 0.895, respectively. Flavonoids apigenin glucoside, quercetin, and luteolin 7-O-glucoside showed correlation ($p < 0.05$) but with lower Pearson´s coefficient values ranging between 0.85 and 0.69. Besides, no correlation was found between quercetin 3-O-rhamnoside and antioxidant activity.

Table 2. Average concentrations and standard deviations (n =3) of the principal phytochemicals quantified in pulp, peel and fiber from peel of ripe mango Ataulfo expressed as mg·100 g^{-1} (Dry basis).

Component	Pulp	Peel	Mango peel fiber
Quinic acid	128.5 ± 18.4^{c}	3244.0 ± 402 ^{a}	263.4 ± 35.3^{b}
Ferulic acid	91.5 ±18.4^{c}	2649.6 ± 221.6^{a}	220.2 ± 9.9^{b}
Galic acid	5.3 ± 1.1 ^{c}	149.2 ± 29.2^{a}	16.2 ± 2.1 ^{b}
Coumaric acid	0.54 ± 0.09^{b}	5.56 ± 1.6^{a}	0.46 ± 0.05^{b}
Mangiferin	0.8 ± 0.1^{c}	1728.7 ± 213^{a}	752.1 ± 38^{b}
Quercetin	0.04 ± 0.0 ^{c}	4.0 ± 0.25^{a}	2.5 ± 0.26^{b}
Luteolin 7-O-glucoside	0.02 ± 0.0^{c}	0.54 ± 0.04^{a}	0.35 ± 0.07^{b}
Apigenin glucoside	0.01 ± 0.0^{c}	0.35 ± 0.05^{a}	0.18 ± 0.06^{b}
Quercetin 3-O-rhamnoside	ND	0.26 ± 0.05^{a}	0.19 ± 0.03^{b}

Different superscript letters indicate significant difference between treatments ($p < 0.05$).

Table 3. Overall antioxidant capacity evaluated by ORAC, FRAP and ABTS assays for pulp, peel and peel fiber of ripe mango Ataulfo.

	mMol TE/ g		
	ABTS	**FRAP**	**ORAC**
Pulp	7.08 ± 1.1^{b}	98.87 ± 11.2^{b}	7.08 ± 1.7^{b}
Peel	372.9 ± 42.7^{a}	252.14± 16.6^{a}	347.97 ± 9.8^{a}
Peel fiber	8.5 ± 1.2^{b}	82.21 ± 10.9^{c}	9.25 ± 2.1^{b}

Different superscript letters indicate significant difference between treatments ($p < 0.05$). (TE)= Trolox equivalent, ABTS (free radical of 2,2'-azinobis-(3-ethylbenzothiazoline-6 sulfonic acid); FRAP (ferric reducing ability of plasma); ORAC (oxygen radical absorbance capacity).

Table 4. Pearson's correlation coefficient (r) between antioxidant activities of fractions from mango Ataulfo and bioactive compounds contents.

	ABTS	FRAP	ORAC
Ascorbic acid	**0.745** 0.021	**0.813** 0.008	**0.756** 0.018
β-carotene	**0.705** 0.034	**0.764** 0.017	**0.692** 0.039
Mangiferin	**0.886** 0.001	**0.832** 0.005	**0.895** 0.001
Quercetin	**0.786** 0.012	**0.698** 0.037	**0.783** 0.013
Apigenin glucoside	**0.847** 0.004	**0.760** 0.017	**0.830** 0.006
Quercetin 3-O-rhamnoside	**-0.067** 0.863	**-0.191** 0.623	**-0.083** 0.831
Luteolin 7-O-glucoside	**0.780** 0.013	**0.694** 0.038	**0.774** 0.014
Ferulic acid	**0.998** 0.00	**0.970** 0.00	**0.992** 0.00
Quinic acid	**0.993** 0.00	**0.965** 0.00	**0.984** 0.00
Galic acid	**0.938** 0.00	**0.953** 0.00	**0.990** 0.00
Coumaric acid	**0.909** 0.00	**0.919** 0.00	**0.960** 0.00

(TE)= Trolox equivalent, ABTS (free radical of 2,2'-azinobis-(3-ethylbenzothiazoline-6 sulfonic acid); FRAP (ferric reducing ability of plasma); ORAC (oxygen radical absorbance capacity).

DISCUSSION

The present research focused on comparing the nutraceutical potential of three mango Ataulfo by-products based on their nutritional and phytochemical profiles and *in vitro* antioxidant activity. Mango Ataulfo fruit is a good source of macro and micronutrients like other fruits; regular consumption can provide significant requirements of vitamins, minerals, dietary fiber, energy, and a minor supply of protein and fat. The U.S. Food and Drug Administration (FDA) recommends a daily vitamin C value of 90 mg for adults; thus, 10 g of mango Ataulfo pulp or peel provides 74% and 100 % of vitamin C, respectively [40].

Excessive sugar consumption is associated with obesity, metabolic disorders and chronic degenerative diseases. The WHO recommends limiting the intake of foods with a high content of available sugars to prevent sugar intake from exceeding 10% of total energy intake [41]. The high sugar content in mango pulp makes its use limited in nutritional programs, however, precisely the proven beneficial effects of mango consumption in the prevention of metabolic disorders, diabetes and cardiovascular diseases seem to contradict this paradigm. There is controversy between those who propose a greater consumption of fruits and those who suggest limiting the consumption of fruits rich in fructose such as mango, since fructose has been associated with a higher incidence of diseases such as hepatic steatosis, cardiovascular diseases and cancer [42].

On the other hand, the combination of dietary fiber and available sugars characteristic of fruits such as mango, confers it a low glycemic index. The higher proportion of dietary fiber and lower glycemic index is related to a decrease in molecular markers of inflammation [43]. Mango peel had a better nutritional profile than the pulp, as it contains fewer available sugars and significantly higher dietary fiber content, suggesting that it has a lower glycemic index. Compared to pulp, mango peel also contained considerably higher amounts of all bioactive compounds evaluated (vitamin C, provitamin A, phenolic acids, flavonoids and mangiferin).

The beneficial properties of mango are due to the abundance of phytochemicals with structures that promote ROS scavenging and that intervene positively in reducing or inhibiting the production of proinflammatory cytokine [14-15,23]. Therefore, it would be expected that the differences in the composition of the mango fractions evaluated could exert different biological functionalities depending on the natural combination of bioactive compounds they contain; future research work could be oriented in that direction.

The study of the chemical composition of mango peel has gained relevance in recent years because it is an abundant source of bioactive compounds wasted during industrial mango processing. The comparison of Ataulfo, Tommy Atkins, and Keitt mango peels highlights the Ataulfo cultivar as the most prominent source of dietary fiber and total phenolics [44]. The content of flavonoids and phenolic acids in the peel of Ataulfo mango was also higher than that of Haden, Manila, and Panamanian mango [27].

Despite the large number of studies on the beneficial effects of mango bioactive compounds, a recent and extensive systematic review states that there is not enough scientific evidence to support that mango consumption is effective as an antidiabetic in humans; it also suggests that the effect of the different varieties of mango used in the investigations; differences in nutritional composition and bioactive compounds are likely to contribute to the discrepancy on results [45].

Mango peel fiber is a dietary fiber concentrate derived from the solvent extraction of soluble components. The peel fiber isolated from mangoes represents a good quality source of dietary fiber, considering the balance in the proportion of soluble and insoluble fiber that characterizes it. This by-product of mango could be useful to enrich low-fiber foods and increase their technological and nutraceutical functionality [30]. Adequate consumption of dietary fiber is associated with decreased blood cholesterol, lower risk of CVD, and a healthier gut microbiota [5,46].

The differences in the composition of the various mango cultivars or the different parts of the mango fruit become relevant when used in experiments to observe some physiological effects. When a certain portion of mango pulp or peel is established in an experiment, the dose of the components that will impact the study model is based. In the same way, the quantification of nutritional and bioactive compounds of the different parts of the Ataulfo mango (pulp, peel, and peel fiber) will allow subsequent interventional research to determine doses of bioactive compounds.

ABTS, ORAC, and FRAP antioxidant capacity tests are considered biologically relevant and are widely used, as they collectively assess hydrophilic, lipophilic, and reducing potential in both foodstuffs and biological systems under physiological conditions. The results of the three antioxidant capacity tests did not indicate a predominant antioxidant mechanism in the different Ataulfo mango products. This is possibly due to interactions between the different antioxidants and potent reducing compounds in Ataulfo mango products. In this sense, the antioxidant activity and the *in vitro* results confirmed the superior potential of the functionality of mango peel with respect to mango pulp and peel fiber. These results confirm those previously reported when compared nine mango varieties [47]. The

results of the correlation between antioxidant capacity and the different bioactive compounds are also consistent with those reported for mango peel and kernel [28]. We agree with these authors that mango peel is an ideal ingredient to be used in the preparation of functional foods that help improve overall health. In this regard, work has been done adding mango peel powder to the preparation of some processed foods such as bread and yogurt [48-49].

Mango peel also represents an important source for the extraction of specific compounds such as mangiferin. Mangiferin is perhaps the mango component with the most research regarding extraction and purification methods [21,50], therapeutic effects [51-52], mechanisms of action [53,54] and pharmaceutical forms [24-25,55]. Another compound abundant in mango peel is quercetin, which could be explored as a nutraceutical, since it is the most abundant flavonoid in mango peel and its remarkable antioxidant capacity has been widely proven on inflammatory and metabolic disorders [56-57]. However, further studies are required to support the requirements to be considered as a functional food ingredient [58].

In summary, the results of this work showed that mango Ataulfo peel is a promising combination of high diversity and quantity of bioactive compounds like dietary fiber, vitamins, and phytochemicals, all of which have proved to have beneficial health functionalities; the mango Ataulfo pulp, on the other hand, offers both bioactive compounds and sugars that could contribute to raising the sensory and nutraceutical quality of foods. Nutritional and chemical characterization allowed us to know the proportion of the different compounds in the natural state of each part of the mango fruit.

CONCLUSIONS

The composition of mango peel offers a rich combination of mangiferin, flavonoids, phenolic acids, vitamin C, provitamin A, and dietary fiber, all of them associated with the prevention of diseases related to inflammation and oxidative stress. These results support the exceptional nutraceutical potential of mango peel due to its superior antioxidant capacity.

Furthermore, its high dietary fiber content suggests potential health benefits due to the well-known properties of dietary fiber to stimulate the growth of beneficial gut bacteria, regulate blood sugar levels and reduce cholesterol.

It is highly recommended to conduct some *in vivo* studies in the near future to demonstrate whether the consumption of these three different mango by-products will actually improve the symptoms of diseases related to inflammation and oxidative stress, according to their respective nutritional and nutraceutical composition and antioxidant capacity.

Abbreviations: ROS: reactive oxygen species; HPLC: High performance liquid chromatography; TEAC: Trolox Equivalent Antioxidant Capacity; FRAP: Ferric Reducing Antioxidant Power; MPF: peel isolated fiber.

Competing interests: The authors declare no conflict of interest.

Acknowledgment: The authors thank MC. Pedro Bastidas and Dra. Laura Contreras for their valuable technical support in chromatographic analysis, and MC Cristina Alicia Elizalde for its support in antioxidant capacity tests.

Authors´ contributions: Conceptualization, MVJ, JAS and RVR; writing, RVR, JAS and MVJ; writing—review and editing, JAS, MVJ, CCQ; supervision, CCQ, FCT, ETC; project administration, MVJ and JAS. All authors have read and agreed to the published version of the manuscript.

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